Fermilab

TM-1131
2300.000

CONTEMPORARY DATA COMMUNICATIONS AND LOCAL NETWORKING PRINCIPLES*

Greg A. Chartrand

August 1982

*Submitted to the Seventh International Nathigali Summer College on Physics and Contemporary Needs, Islamabad, Pakistan, August 15-19, 1982.

1.0

INTRODUCTION

This paper is viewed from the perspective of the basic elements that comprise any communications circuit, and this viewpoint is carried through from beginning to end. Because of this approach, this paper does not intend to be the definitive source of information for computer networking, but will attempt to serve as a primer for those who wish to pursue specific areas of interest.

To begin, I think it is important to look at the unprecedented growth of computing in general over the last 20 years. The computer's power has increased almost exponentially relative to size, cost, and resources used. Technology has been the vehicle of computer's power growth, but data communications has not grown at a rate anywhere equal to computer's. The same technology that has accelerated computer's growth has not influenced data communications as drastically even though they use the same basic components. This stunted growth has been due to many factors; governmental regulations, the lack of universally accepted standards, and inter-dependency on computer power are a few worth mentioning. Today these and other moderating factors have diminished and the data communications arena is set for many technological battles and very fast growth.

The most important issue of data communications today is networking which can be roughly divided into two catagories;

1) Local networking.
2) Distributed processing.

The most sought after aspect of local networking is office automation. Office automation really is the grand unification of all local communications and not of a new type of business office as the name might imply. This unification is the ability to have voice, data, and video carried by the same medium and managed by the same network resources. There are many different ways this unification can be done, and many manufacturers are designing systems to accomplish the task.

Distributed processing attempts to share resources between computer systems and peripheral subsystems from the same or different manufacturers. There are several companies that are trying to solve both networking problems with the same network architecture. At the end of my paper, I will address this unification in greater detail.

As you will see later on, the distinction between these two items has begun to diminish.

2.0

COMPUTER COMMUNICATIONS HISTORY

My intent is not to give a paper on the history of communications or computing, but a historical perspective will be useful in understanding how data communications has evolved to its current state. The history I am describing is derived from the perspective of data communications, and thus any historical distortion of computer history is strictly intentional. I would first like to preface my comments to say that universally I have found that as complicated as we make computer and or communications systems, the roots of these systems generally go back to very simple ideas and concepts that are easy to understand. Computer communications is a prime example of an adaption of old technology and concepts to new applications. The real history of computer communications goes back to the days of the telegraph before the turn of the century. Although the central processor of those communications systems were human, the ideas, purpose, and most of the techniques are still the same. In any communications system there needs to be the following basic elements:

1) A medium to carry the data.
2) Devices to transfer data on and off of the medium.
3) Rules to govern and control the flow of data.

Traditional computer data communications began in the 1950's when what we know today as remote batch stations were born. Probably the need for these stations grew out of the need to get all of the people out of the computer room so some work could be done. When the card reader and line printer left the computer room, the need to have these work stations located further distances from the computer room increased. As a result of this need, modems were developed to utilize telephone lines as the medium to carry the data. Modem is an acronym derived from the terms MODulate and dEModulate, which is what a modem does over a telephone circuit. Telephone systems were, and are today, not specifically designed to carry data, so the modem is the transfer device which adapts the digital signals of the computer to the analog world of the telephone system. This adaption in the the beginning used very simple modulation techniques to achieve communications. As the need grew for higher speed communications, the complexity of the modulation waveform followed suit as more and more bits per second were pushed through telephone systems. And as one might expect, the probability for errors increased right along with the speed and length of transmission. So to detect and recover from these errors, software had to be developed. Additionally, there was a need for several work stations to share the same telephone circuits to increase the utilization of the circuits. These software needs evolved into what we now call protocols which are the rules that govern the format of the data to be exchanged between the central processor and the remote equipment. Due to a lack of standarization, protocols were defined by the manufacturers. This vendor dependency has historically led to the evolution of many different protocols, and as in nature, some have survived and still prosper, and others are now extinct. The surviors of this evolutionary process have been adapted by the computer industry sometimes intact, or in some cases, have spurred mutations that have been successful. The execution of the protocol, and the transfer of data to and from the central processor requires computation. In the beginning there wasn't much computer power to go around, so protocols were written to be very simple and efficient. Simple and efficient also implies unintelligent, unforgiving, and inflexible.

These batch protocols allowed for remote submission of jobs to be run on a central computer system, and printed output to be received, but modification of programs and creation of new programs was cumbersome because the universal input medium was punched cards. I don't intend to completely discard punched cards as a viable medium for program storage, but I'm sure all will agree that the end of cards is near. So clearly there was needed a better way to maintain programs, and this need created interactive computing. The first interactive computing systems placed teletype equipment remotely connected to the computer, again using telephone lines as the medium and modems as the transfer devices. As telephone systems technology grew, the ability to have a rotary of several telephone numbers allowed for simple and relatively efficient use of the communications ports of the computer. Early interactive computer systems were very crude and many treated the computer user as if he was still working with punched cards. The user could maintain his programs interactively, but the computer system still was working like a batch machine, and truly interactive computing where the user actually interacted with his application program took a long time to evolve. I might say that even today there are computer systems that still have carried over a pseudo batch user interface. Further exploration in this area can be had by studying the history of computer operating systems. Multi-dropping of terminals on a single communications circuit now allowed for telephone lines to be used more efficiently, but now the terminal required more intelligence because it had to recoginze its individual address. This sharing of resources was accomplished by a new set of rules or protocols which additionally provided for retransmission if the data was received in error.

3.0

LOCAL NETWORKING ELEMENTS

Computer local networking is the fastest growing area of data communications, and the most complicated. To try and keep local networking understandable, I will first describe the basic components and techniques that are used to build networks before we look into today's networks.

As I mentioned before, any communications system needs the three basic components, medium, transfer devices (for the medium), and rules. Computer networking has these basic needs as well. All networks do not use the same items for these three component needs. The specific component needs of the network are defined by the networks architecture, and the architecture is the variation of the three component parts for the specific network defined by the designers hardware and software. In networking, one finds it difficult to draw the line between the hardware and software. This is so because both are designed together to accomplish the transfer of information thru the selected medium, and thus the designers of network components will try to minimumize effort and or price to accomplish the desired task by shifting the border line between hardware and software to do so. Classic examples of this shift can be seen in today's network components where contempory designers are taking advantage of microprocessor technology, thus shifting the border from hardware to software. As microprocessor technology continues to advance, networking components will continue to be more software oriented (from the designers point of view). Microprocessor technology can even invade the traditional analog world of the modem with digitally programmable filter networks. So the trend currently is to incorporate the newer technology components into old networks as well as to create new types of components for new networks.

3.1

MEDIUMS

For the purpose of this paper, I will restrict the definition of medium to be the intervening element between points in a data communications circuit. The medium for a network is usually determined by the network selected for use, and not by the user of the network, mostly because the different mediums have individual characteristics that have to be accomodated for in the other elements of the communications circuit, I.E. the transfer devices and the rules or protocol. So for the most part, the medium becomes integral to the network itself. Some of the newer networks designs are attempting to have multi-medium capabilities, with the primary medium intergal to the network, and interface capabilities to other mediums at fixed points in the network, thus allowing for additional flexibility.

For data transmissions, a medium can be used in two different ways;

1) Baseband.
2) Broadband.

Baseband implementation of a medium implies direct transmission of digital data on the medium, and broadband implies the use of carrier(s) to represent the digital information on the medium. Broadband also allows for multiple simultaneous communications channels to share the medium at the same time by using different carrier frequencies. There are many mediums that are used for transmission of data. The mediums I will discuss are the following;

1) Twisted Pair Wires.
2) Coaxial.
3) Fiber Optics.
4) Satellite circuits.

3.1.1 Twisted Pair Wires

Twisted Pair Wires (TPW) were as I have mentioned earlier, the first medium to be used in networking, and of course TPW's also imply the use of telephone systems. As a medium, TPW's are used both in a baseband and a broadband sense. In terms of today's utilization of TPW's, baseband implies using 20 MA (milliamp) current loop, RS-232C, or RS-449 compatible drivers and receivers. I will discuss these three types of baseband standards later on. Baseband use is restricted to either local wires or special point to point telephone circuits. Broadband utilization for TPW's generally implies using modems to modulate and demodulate the data. It is the use of the modems that allow transmission through a switched telephone network using voice grade lines. TPW's generally are thought of as a low speed medium, mostly because use of TPW's historically is associated with modem use and thus limited to the bandwidth of a voice grade telephone circuit. It is possible to drive TPW's to speeds in excess of 1 Megabit baseband, but the lack of effective shielding makes this impratical. Shielded TPW's get around the problem, but if a shield is to be used, then one might as well use coax. So to summarize, TPW's are the most widely used medium and have many international standards that are associated with its use, but they are typically associated with slow speed circuits and generally do not have good noise immunity.

3.1.2 Coaxial Cable

Coax is the medium that is very popular in contemporary network designs even though it has been around for a long time. 75 ohm coaxial cable has become the most popular of the newer designs mostly due to the cable television industry (CATV) which exclusively uses 75 ohm cable. This has lowered the cost of this variety of cable and also allows for compatibility with CATV components which I will discuss later in more detail. Its largest advantages over TPW's is its shielding which can provide great noise immunity, and bandwidth that is over 100 times wider than TPW's.

Coax, like TPW's, can be used in either baseband or broadband mode. Because coax is incompatible with telephone systems, there are no frequency limitations implied in its use. Thus baseband applied to coax relates mostly to the kind of multiplexing that is used in conjunction with the medium. I will discuss the different multiplexing techniques further on in this section.

Baseband implementation of a coaxial medium implies that the medium will be a shared resource among several different transfer devices. There are several different ways this sharing can be accomplished, and they will be discussed in the multiplexing section.

To summarize, coax does provide for higher speeds of transmission, has better noise immunity, and can be used to provide more than one communications circuit at the same time.

3.1.3 Fiber Optics

Fiber optics is the very latest medium that can be used for data transmission. The advantages it offers over other mediums are extremely large; isolation from outside influences, potential for very large bandwidths, and very small size. The problems associated with its use are mostly due to the fact that it is new and technology has not yet fully exploited the capabilities of the medium. Although the potential for very fast speeds is inherent in fiber optics, it is not yet pratical for broadband use and must be used in baseband mode. Thus one ends up having one very fast circuit that has to be shared, and to effectively share the circuit, very fast electronics has to be used at each point of connection, and this becomes expensive. There are also problems that have to be solved in interconnection at the point of use, and re-amplification of the light signals so greater distances can be covered.

To summarize fiber optics use as a medium, it can provide for very high data rates and extremely good isolation, but is currently difficult to interconnect to and to extend distances.

3.1.4 Satellite Circuits

Satellites by themselves do not comprise a medium per se, however using a satellite channel for communications has specific implications that are unique, and thus have to be treated differently. The most noticeable difference satellites present are their physical locations. Most all communications satellites are located in geo-stationary orbits, that is they are stationary relative to the ground over the equator at a height of aproximately 22,000 miles. It is this distance that creates the largest problem for the data communications channel because the round trip time for a data message can be delayed several hundreds of milli-seconds. This delay for a voice circuit may just be an annoyance, but for data it can be fatal. The amount of damage the delay causes depends mostly on the rules of the protocol in the data circuit. Degradation of performance can be as much as 70% if the protocol used requires an acknowledgement of every data message, as is the case in many of the older protocols. Special hardware can be used on each end of the circuit to get around most of this problem, but the problem is still there and will always impare the real-time response of the network. Because there are fewer active components in a satellite circuit, they tend to present a very reliable means of transmission where the distances are great.

So to summarize, satellite circuits as a medium provide a very reliable means of long distance transmission, but the propagation delay may create difficulties if the protocol of the data circuit is not prepared for it.

3.2

MEDIUM TRANSFER DEVICES

Medium transfer devices are used to encode and decode the digital data on to and off of the medium. Because of the many different kinds of networks, these devices vary widely in complexity and purpose. A general distinction can be made between baseband and broadband transfer devices.

Baseband transfer devices only have to be concerned with the data activity of a single communications channel, so it is looking at digital messages and/or addresses on the channel to determine if it is supposed to respond to or be able to generate messages on the medium. Baseband transfer devices can connect to all of the mediums previously described. Their physical and electrical connection to the medium vary widely depending on the actual network and medium type. Coaxial baseband transfer devices that use coax as a medium connect to the coax in two different ways, active and passive. The active connection is used by ring network designs that need to place intelligence at the point of connection. The passive connection to the coax has no active components at the point of connection, just an electrical connection. CSMA/CD networks use this method, and this will be discussed in detail in later sections.

Broadband transfer devices can be divided into the two following categories:

1) Voice grade compatible Modems.
2) Radio frequency (RF) modems.

Both types of these modems have the problem of adapting an analog environment to digital equipment.

The voice grade compatible transfer devices are referred to as the traditional modem, and usually use TPW's as a medium. The modems will generally assign audio carrier frequencies to serve as either the carriers to be multiplexed into a higher speed by splitting the data between the carriers and recombining them at the other modem, or to use the separate carriers as independent data channels so that transmitted and received data can occur simutaneously (full duplex). In either case, the carriers are amplitude, frequency, or phase modulated to represent the data on the carriers.

RF modems are relatively new devices that place individual carriers that represent different data channels on the medium. RF modems are used in coaxial, satellite, and microwave communications circuits.

3.3

SIGNAL STANDARDS AND PROTOCOLS

There is a great need for international recognition for standards of both signals and protocols on a world-wide basis. To do so, organizations have been formed to define these standards. Most of these organizations have committees that are continuously working to define new standards for many purposes in and out of the data communications field. In some cases a manufacturer's defined standard will be adopted directly or modified to be more general in nature by a standards organization. Other times, the standards will be purely the product of a committee within the standards organization. The following is a list of some of the standards organizations, and their associated letter designators for their defined documents:

ORGANIZATION	DESIGNATORS
Electronic Industries Association	RS-(nnn)
International Telegraph and Telephone Consultative Committee (CCITT)	X.(nn), V.(nn)
American National Standards Institute (ANSI)	ANSI (nnn)
Institute for Electrical and Electronic Engineering (IEEE)	IEEE (nnn)
International Organization for Standardization (ISO)	ISO (nnn)

Signal level standards define the physical and electrical characteristics of the data connection. This would include everything from the physical connector and pins to the sink current on a signal level. Control signaling definitions are also covered in these strandards.

All throughout this paper I have been using the words rules and protocols as equivalents, and for data transmission this is so. As I mentioned in the History section, the rules were developed initially for error recovery and telephone line sharing between several different work stations. Some protocols are most efficient when data activity through the medium is bursty or intermittent in nature. Others perform better when the data is in long continuous streams. Some try to optimize themselves for both types. In reality, the protocol will be optimum for a particular mix of data activity, and selection of a network based on other characteristics of the protocol will guarantee you to compromise your objectives in data transfer. In truth, the most efficient protocol is the one that you have designed for your particular needs. Of course there are many difficulties associated with taking on a task like this, but if your application demands it, you can define your own rules.

3.3.1 Signal Level Standards

As I stated in the history, the lack of international standards has slowed the growth of data communications. Over the years, there have been a few standards that have been accepted and some that have not. The following is a list of some standards that are internationally used:

1) 20 MA current loop.
2) RS-232C or V.24 and V.28
3) RS-422A or X.27, V.11

These standards are intended for twisted pair medium and thus apply mostly to telephone like networks.

3.3.2 Current Loop and ASCII Standards

20 MA current loop is not a written standard per se, but it's historic use is simple enough that there are few variations from the basic principle. As you may recall from the history section, teletype equipment was the first interactive device for the computer and was connected to it using current loop. In a teletype, there are selector magnets that when released will sequentially select the character that is to be printed. The most used bit pattern that defines the specific character set is called ASCII (American Standard Code for Information Interchange). There are other bit patterns such as EBCDIC which is used mostly by IBM, but ASCII is the most universally accepted. Each character must be framed by a start bit which tells the teletype to release the selector magnets for the 8 data bit's to follow, and a stop bit which tells the teletype that the character is finished. This type of framed transmisson of characters is called asynchronous. The "20 MA" in this type of transmission refers to the amount of current required to hold back the selector magnets in the circuit when no data is being sent or received. So in a current loop circuit, the current is always adjusted to 20 MA independent of the losses required to drive multiple devices or long runs of wire.

3.3.3 RS-232C

RS-232C is today's most generally used standard for interconnection of terminals and modems to computers. This standard defines signal levels and control signals for interconnection of modems to computers and modems to terminals. Because this is a universal standard, it allows for transmission of asynchronous data as in current loop, and also synchronous data. For the purpose of simplicity, I will define synchronous data as data that is not framed as in asynchronous, but still requires synchronization. This is done by the modem providing the clock signal that tells the terminal and computer port when the data can be sent. Synchronous data connections are more efficient because they do not have to transmit the additional 2 bit's required to frame each character of data as in asynchronous.

Because this standard defines voltage levels for transmission, there are inherent limitations as to the distance that can be covered. The standard allows a maximum of 50 feet between the modem and the equipment. Of course the modems have no distance limitations between themselves. The European equivilant of this standard is called V.28 and V.24.

3.3.4 RS-449A

RS-449 is a standard intended to be an ultimate replacement of RS-232C that allows for upward·compatibility. The major features of this standard over RS-232 are the following:

1) Distances greater than 50 feet.
2) Multidrop on one set of wires. (Line sharing)
3) Data rates up to 10 megabits/second.
4) Higher noise immunity.

This standard, although offering nice features over RS-232C, has been very slow to be accepted and few manufacturers have implemented it. This has been mostly due to the increased cost of components required to implement this standard, and competition from RS-232C compatible devices that extend it's capabilities. Other competition has come from the new baseband and broadband networks that essentially cover this standard and do more as well.

3.3.5 Protocols For Data Link Control

The earlier protocols were developed by the computer manufacturers to interconnect their own remote equipment to their computer systems. Because there were no standards, each manufacturer designed the protocol to solve only their own problems. This generally makes the remote equipment very specialized and incompatible between manufacturers. Fortunately, today the emphasis is on using standards for protocols defined by international concerns. This cooperation, whether done in the spirit of cooperation or for practical reasons, has allowed data communications to grow in very specific directions for all communications products.

Because the earlier protocols intended to use TPW's as a medium, they had their communications speeds restricted to whatever speed modem technology could squeeze out of a voice grade telephone circuit. Additionally, because the early work stations were batch oriented, this dictated to the protocol designers that a communications system would use the full bandwidth of the telephone circuit in one direction. This was consistent with the style of batch operation. To submit a job to the computer, you take your card deck to the card reader, start it up, your program is sent to the computer, and you wait for your output to be printed. This operation just described was performed in a half duplex fashon. So half duplex is really transmission designed to occur in one direction at a time. The modems working with the protocol allocate the entire bandwidth of the medium in the direction of the desired transmission.

Most modern protocols can run in full duplex, which of course is transmission of data in both directions at the same time, and some of them can actually run both in half or full duplex. Full duplex may not be as efficient in transmission in a single direction, but today's data communications problems are different than the days of remote batch operation, and full duplex in some cases is necessary to take advantage of newer multiplexing techniques and to provide for real-time response.

Protocols for data link control have the job of passing frames of data using one of the previously mentioned signal level standards. They also have the job of decoding the particular address of the devices it is attached to, and do the task of error detection and correction. These Protocols can be divided into two catagories, bit oriented and byte oriented. The differences between these two types are that the byte oriented protocols use special control bytes to define a data frame instead of several bit's of data as in bit oriented protocols. A data frame for the purpose of this paper is the actual data to be transferred surrounded by or framed by the protocol control information. So in the case of the bit oriented protocols, more control information is contained in the bits, and less protocol overhead is usually involved. Each control protocol has it's own control information contained in the frame. The functional efficiency of any protocol will depend on the appliction, type and amount of data being sent.

3.4

MULTIPLEXING

Multiplexing techniques are the rules defined by the network architecture for sharing the transmission medium. These rules may or may not be incorporated into the protocol depending on the type of multiplexing being used. The three major types of multiplexing are;

1) Time division multiplexing.
2) Statistical multiplexing.
3) Frequency division multiplexing.(Or Radio Frequency multiplexing)

3.4.1 Time Division Multiplexing

Time division multiplexing allows for time sharing of a single data channel for multiple data links. So within the protocol are rules that allocate a specific time slot to a specific device or channel within a time division multiplexor. The number of time slots are always equal to the number of devices or channels sharing the medium. This method of sharing is most efficient when all devices using the medium are being used, and are transmitting data. Because the medium is allocated 100% of the time, inefficient use occurs when devices or channels are inactive or do not have data to send.

The most popular type of network inplementation of this kind of multiplexing is called a token passing or ring network. In this kind of network, a special protocol message called the token is passed around from device to device by a network master device on the medium. When a device has the token, it can then send data if it has to. Special protocol intelligence is needed for the network if the token is lost. This usually will occur if a device on the network is not functioning, so the network has to know how to bypass the unresponsive device. This dependency on a single point of intelligence is one of a ring networks drawbacks. One other point of interest with ring networks is their medium transfer device which requires that there be active components in it. This allows for a single point of failure for the whole network in each interface device. Most ring network designs have bypass circuitry that helps the network to survive having an interface device powered down. But because there are active components in the system, and the ring requires every interconnection device to respond, the whole ring itself becomes a failure point for the whole network. This requirement that the ring be closed also might pose problems with configuring the network since each interface device is strung in series. I might comment that these potential failure modes do not have a high probability of occurrence and should not be an ultimate factor in selection or design of a network, but they are worth consideration. An advantage of the active connection is that the signals on the coax are regenerated by the interconnection device. This allows for cleaner transmission of signals on the coax, and that should equate into a lower error rate.

3.4.2 Statistical Multiplexing

Statistical multiplexing can be looked at in several ways. Basically, statistical multiplexing allocates the medium to devices as the need to transfer data happens. There are devices designed to use this technique using standard network components and terminals, that allow for sharing of what would normally be a single circuit for a single terminal, by several terminals. Because the bandwidth of the medium is dynamically allocated, the efficiency of this multiplexing technique is very high. Many manufacturers of data communications equipment have statistical multiplexors that provide virtual terminal connections from point to point. Most of these devices are ASCII and RS-232C compatible.

A new type of statistical multiplexing that is going to be used extensively in the near future is called CSMA/CD. That stands for Carrier Sense Multiple Access with Collision Detection. In this kind of statistical multiplexing, devices on the network monitor the medium for data activity, if they have data to transfer and detect no activity, they then place the data on the medium. The data is encoded with the address of the receiving device, so once the data is on the medium, only an acknowledgement from the receiving device is necessary. If two devices detect no activity on the medium and transfer their data at the same time, a data collision will occur. Both devices will know what has happened because they will have monitored and detected the garbled data. They will each wait a random amount of time and then retransmit their data. This multiplexing technique has been developed by XEROX Corporation, and is incorporated into a network archetecture known as ETHERNET.

3.4.3 Frequency Division Multiplexing

The basic concept of frequency division multiplexing is to consider the medium as the full spectrum of frequencies up to the maxium practical frequency.

As frequency division multiplexing has been described earlier, it allocates a carrier frequency on the medium to represent each device so devices have continuous non-shared connections from point to point.

RF transceivers (transmitters and receivers) are used for the medium transfer devices to provide the data channels. They use any of the known modulation techniques to acomplish the task, but most of them utilize frequency modulation (FM).

As carriers are allocated for data channels, the problem of sharing data between devices becomes more difficult because each device having it's own specific carrier frequency dictates that devices that exchange data must listen to the individual carriers. Thus RF frequency division multiplexing is very good for providing multiple independent point to point data links between two devices, but sharing of a single communications channel is very difficult. Additionally, the introduction of another technology, namely CATV, adds to the problems of interconnection. CATV components and distribution is an entity all to itself, so using them adds another foreign technical field into the data processing environment.

3.4.4 PABX Sharing

PABX sharing is not really a recognized means of multiplexing and in fact by it's nature, it is anti-multiplexing. The reason it belongs here is that if properly managed, it does achieve the same final goal of multiplexing, namely increased utilization of computer communications resources.

PABX is a telephone term for <u>P</u>ublic <u>A</u>ccess <u>B</u>ranch e<u>X</u>change. This term refers to the telephone equipment switch that does the allocation of telephone circuits to telephones. The switch has a fixed number of circuit's it can allocate to a larger number of telephones. So it relies on the premise that all telephones will not be in use at any one given time. One might refer to this as probability multiplexing. The number of circuit's that the switch has to allocate, must allow for peak activity, and flag the user if all of the circuit's are busy. In data communications terminology, these devices are referred to as a port contention devices, or port selectors.

The operation of a port selector is very similiar to the concepts of a telephone PABX. When you pick up the receiver, you are communicating with the network controller. It expects you to provide an identifier that tells it which other telephone you want to communicate with (by dialing). Then a connection is established for you. When you finish, you hang up the phone thus terminating your connection so the circuit can be used by another phone. The data equivalent of the PABX works exactly the same way. Your data connection is established by you communicating with your terminal to the network controller, which is a microprocessor that establishes the computer connection and so forth. Once the connection is established, the network controller does not get involved in the actual transmission of the data, just as in a telephone system.

The type of network that is associated with the use of these devices is called a star network. A star network branches out from a central location (where the port selector is located) and each device in the network is individually connected the the switch. One of the major drawbacks of this type of network is the fact that there is one central piece of equipment in the network (the switch) that, if it fails, will stop the function of the whole network.

As you may have suspected, most port selectors use TPW as a medium, and use current loop or RS-232 signal standards..hl1;NETWORK TYPES

Now that all of the terms I will use have been defined, I hope we can now move foward into the various network types that exist today. I would at this time like to associate network types with specific vendors names, not to promote specific vendors, but in networking, these are the names that are referred to, not the actual network type.

Because there are so many variations one can contemplate by selecting different mediums, transfer devices, and protocols, I am going to concentrate on just two now that have different attributes and amplify their differences. The two that I will discuss are the following:

1) ETHERNET
2) SYTEK

These two were chosen for further discussion because they represent the most state-of-the-art in network concepts, and use different types of multiplexing even though they use the same kind of medium.

3.5

ETHERNET OVERVIEW

XEROX Corporations ETHERNET is one of the first widely accepted baseband networks. XEROX invited other manufacturers to use ETHERNET in their own designs. For a while it looked like ETHERNET might not become the standard baseband network due to competition from the Institute of Electrical and Electronic Engineerings (IEEE) proposed standard IEEE 802 which was similiar to ETHERNET, but different enough fundamentally to not allow compatibility. Recent changes in the IEEE standard will allow XEROX to redefine ETHERNET to adhere to the standard. This marriage between the two standards will assure that both will survive. Other computer manufactures are in the process of building interfaces to ETHERNET. This will allow for vendor independent transmission some day, and possibly vendor independent distributed processing at some level.

ETHERNET uses CSMA/CD statistical multiplexing which I have discussed in multiplexing.

ETHERNET uses 50 ohm coax for a medium, and the interconnection device is a passive tap on the coaxial cable with no active components involved. This last point is particularly interesting because it allows a considerable amount of flexibility in interconnection. That is, the coaxial cable does not have an in and out connection so the interface devices do not have to be wired in series. The other major advantage to this approach is that an interface device may fail or be powered off and not affect the rest of the network. ETHERNET runs at a bit speed of 10 megabits/sec and has a 2.5 kilometer distance limitation.

3.6

SYTEK OVERVIEW

SYTEK INC. has developed a broadband coaxial local area network that relies on CATV devices for distribution. The SYTEK network is similiar to the IEEE's 802 standard for broadband local networks. The part of this standard that has been finished is mostly concerned with the allocation of the coaxial spectrum. Small variations between SYTEK's network and the standard are present, but both accomplish the task of defining a two-way single coaxal medium. Each data channel's frequency assignment can provide a virtual connection between two points on the network. The major rules in this network relate to the RF requirements of the CATV compatible components.

The most interesting aspect of this type of network is the fact that the spectrum of the medium is divided roughly in two parts to define transmission of data to and from the interconnect device. This bi-directional separation is called a mid-band split. The split assigns a guard band of spectrum between the two directions, and allows for amplification in the two separate directions by the use of special filtering within the amplifiers. At a central location within the network, a head end has to be established. A head end is a term to describe a point where the signals reverse direction. So all devices send their signals to the head end where the frequency translation from high side split to low side split and amplification take place. After translation, transmitted data now becomes received data for the network. This technique is necessary to assure uniform RF performance throughout the entire network.

SYTEK has designed statistical multiplexors along with the RF transceivers to take advantage of both frequency division and statistical multiplexing techniques. This helps to keep the networking costs down by sharing the high RF transciever costs amongst many virtual terminal connections.

The physical interconnect devices for this type of network are specifically CATV directional couplers that allow for interconnection to the medium with a minimal amount of degradation. These passive taps on the medium connect to the interface device which essentially are RF modems. Transmission onto the medium is done by a small radio like transmitter in the interface device, and a small radio like receiver on a carrier frequency separated by the mid-band split is used to get the data off of the medium. The transmitters and receivers are truly modems in that they modulate and demodulate the digital signals.

The interface devices for SYTEK take the demodulated RF information, and convert it to one of the other signal level standards. By doing this, the SYTEK network now becomes transparent to the specific equipment requiring the data channel, as long as that equipment uses one of the other signal standard conventions. This transparency allows for a very flexible mixture of devices and protocols to share the medium at the same time. Because this is a broadband network, each data link (as previously stated) has it's own carrier frequencies, and will function as if there was no network at all in between the devices.

The flexibility of this type of network brings a few problems. One of these is the requirement that the network must be managed by individuals who are trained not only in Data communication, but in CATV as well. The CATV aspects of this type of network are every bit as complex as the actual equipment using the network, so additions and changes to the network require careful planning from an RF point of view as well as a data communications point of view.

3.7

DISTRIBUTED PROCESSING

Distributed processing is a very large and complicated field of computing and data communications. It goes beyond the scope of this paper, so my remarks relative to distributed processing are limited only to those relavent to local networking that can be vendor independent.

Distributed processing can be looked at as a local network that has its peripheral devices and processors linked together as shared resources. So essentially one can look at the system which includes everything attached to it, as a single system even though the resources you are using are attached to a different processor. In these kinds of systems, the network itself becomes integral to the computer system and it is very difficult to determine where the computer system ends and the network begins from the users point of view. This is particularly true as the speed of the network approaches that of the disks and the execution speed of memory. Thus a high performance local network can become the link between processors that can provide increased power of the total computer system.

The design and implementation of the network in a truly distributed processing system can become simple relative to the difficulty of protecting and managing the distribution of the shared data and processes. This problem is a major limiting factor in distributed processing systems, and is not at all related to any limitations of networking.

Distributed processing, although not a new concept, has not been widely used. Most distributed processing systems are not vendor independent. Thus I am reluctant to call these truly distributed processing, and am more inclined to refer to them as vendor dependent integrated computing systems.

4.0

NETWORKING PRESENT AND FUTURE

The present and future of networking are cast into the parameters that I have defined within this paper. All three of the basic elements of networking will be changing as technology catches up with the increasing need for networking. Why should this increasing demand be stressed? The fact is that as computing power has increased dramatically, the cost and size of computers has dropped. The recent history of computing shows that this trend will continue. So in the next decade, the emphasis will change from the need to process data to gaining access to the data that needs to be processed. This shift is what will create the demand for better data communications.

The major networks mentioned, namely ETHERNET and SYTEK, are just beginning to be used. ETHERNET installations will not become widespread until there are integrated circuits designed specifically for the network components. So if one wanted to design a network today using ETHERNET, one would be hard pressed to find components to use for this purpose and would find very little software support from any vendor other than XEROX. SYTEK's components are available today for use, and because they provide the data transparency that is integral to a broadband network, they can be used to build a complete network. Because all of the broadband networks are relatively new, the costs are comparatively high for interconnecting many slow speed devices. As the need for higher speeds increases, the cost effectiveness of this type of network also increases.

4.1

TRENDS IN MEDUIM UTILIZATION

Clearly by sheer numbers, TPW's are the masters of todays networking. The flexibility that TPW's offer over any medium (except for high speed needs) exceeds any other. Its domination of networking will be short lived as baseband, particularly ETHERNET, get a foothold on the market. This transformation will start to occur in the next 5 years as more manufacturers design equipment around ETHERNET's protocol. ETHERNETS popularity will mean that the trend will shift from TPW's to coaxial cable used in baseband mode. As the need for more bandwidth increases, ETHERNET and other CSMA/CD protocols will be commonly used in broadband mode where many individual links of this type can share the same cable using independent carrier frequencies in a frequency division multiplexed environment. With this flexibility, coaxial cable will certainly be the medium to be used in the later 1980's.

Fiber optics will be in use for long distance applications where bandwidths greater than coax are needed. Although most CSMA/CD protocols will easily adapt to fiber optics, the cost of this inefficient use of bandwidth will probably preclude usage of this medium for local networking. Eventually the interconnect and medium costs will be competitive and fiber optics will start taking over coaxial cable in new installations. This will be a long slow process, and I do not believe that it will take place soon for local networking on a grand scale.

4.2

MEDIUM INTERCONNECTION TRENDS

In several aspects, the medium interconnection device issue will determine networking trends as technological advances in this area are made. Presently, this interconnection problem is what is holding back the transformation from TPW networks to coaxial networks. Currently, the relative interconnection costs are as follows;

INTERCONNECTION	APROX. COST U.S. $
Twisted Pair Wires	$200/connection
Coaxal (baseband)	$750/connection
Coaxial (broadband)	$1,500/connection
Fiber optics	$?

As one can see, there is a large spread in cost between the various connection types. The cost for connection to coaxial in both baseband and broadband modes will drop as VLSI (Very Large Scale Integration) devices are designed to contain most of the circuitry for the interconnection devices. Another interesting item to note is that as the bandwidth of the medium increases, the interconnection cost appears to increase at about the same rate.

The costs to connect to fiber optics really have not yet been determined. Because this medium is so new, interconnection standards have not been formulated. Simple point to point slow speed connections can be made today at a very reasonable cost, but in the future I see fiber optics used in one of two ways. First, I see that the cable will be driven in baseband mode at very high data rates, say in the 500 to 1000 megabit range. At these speeds, the bandwidth of the cable will compete with coaxial cable. but at these bit rate speeds, special high speed logic circuits will have to be developed. These circuits will increase the cost of interconnection. Fiber optics will also be used in broadband mode, similiar to the way coax will be used with many possible CSMA/CD data channels sharing the cable with different carrier frequencies. The implication of broadband use of fiber optics also implies some means of linear amplification of light signals within cable, and this has not been acomplished yet.

4.3

OFFICE AUTOMATION

Office automation's primary goal is to integrate all communications facilities into a single network archetecture. This grand goal can only be acomplished through a medium that can provide transparent characteristics to these facilities. This transparency can only be provided in the forseeable future by a coaxial system implemented in broadband mode. Coax has several other potential advantages over other mediums. In the near future, trunk amplifiers for CATV systems will be designed so the useable bandwidth will be increased from 300 MHZ to greater than 1000 MHZ. This expanded bandwidth will keep coax competetive with more advanced mediums for a long period. Implementation of CSMA/CD protocols running in broadband mode gets around one of the major objections of RF multiplexing, and that is inefficient utilization of the medium. Also, integrated circuit implementation of the RF tranceivers that are needed for the interconnect devices will greatly reduce interconnection costs.

CATV coaxial systems were initially designed to carry television and FM radio signals on them. The inclusion of data on these systems does not negate the use of television or radio signals because they are all on different carrier frequencies. So broadband coaxial networks are best suited to provide the grand unification of all communications facilities with a single network. It is possible that there will be a single interconnect device that will have inputs and outputs for telephone, television, and data. Unlike other network types, the technology to do so is already present, and all that is needed is the demand for this kind of integration.

This same integration may also be acomplished by fiber optics systems at a much later date if techniques are developed to digitize the analog signals of video and voice to be multiplexed on to the fiber optic cable in baseband mode. It may also be possible at some future date to frequency division multiplex fiber optics to acomplish what can be done with coaxial cable. However, this speculation goes far beyond todays practical capabilities.

4.4

POTENTIAL DIFFICULTIES WITH LARGE LOCAL NETWORKS

Networking on a grand scale will create new problems with control and management of computer systems that do not currently exist. These problems will be with us for a while until computer systems are structured specifically to address them. The direct problems that grand scale networking will create are;

1) Vulnerability
2) Security
3) Accountability/Resource Management

As the speed of the network increases, more and more devices will be connected to the network instead of directly to the computer system. This distributed peripheral principal will take sensitive equipment out of the protected environment of the computer room. By having high speed networks that connect equipment in this mannor, what is really happening is that the network becomes a virtual extension of the computers internal data paths. If grand scale networking is not looked at in this light, one might place equipment on the network in inappropriate locations. Doing this without due consideration may change the meaning of distributed processing to distributed problems. Having an all purpose network may put the network cable in areas where it might be damaged, and this could be very costly. If there are to be critical devices attached to the network, one should not put the network cabling in places where one would not put the computer buss itself.

Security issues share the same problems as vulnerability issues. Having a large local network shared by a single cable will put all data for all devices accessable where ever it goes. Encryption devices should be attached to equipment that serve security sensitive applications.

Managing and accounting a large local network that is de-centralized may become the critical factor in limiting the capabilities of the network. Without the centralized control and monitoring of the network, troubleshooting and accounting of large networks will become unmanageable.

5.0

DATA COMMUNICATIONS AT FERMILAB

FERMILAB does not use all of the techniques, networks, and devices that I have described, but in the process of determining our needs current and present, we have investigated most networks and network aspects. Because of the size of both our computing facilities and local geography, our communications needs are great. But due to the nature of our funding, the ever present cost effective issues moderate our communications needs to exclude projects and methods that do not pay their way. So in every aspect of what we do in data communications, the need has to be great, and the cost must be justifiable.

5.1

FERMILAB COMPUTING

To really understand what our needs for networking are, it is useful to know the kind of computing we do. So the following will be a brief description of computing at FERMILAB.

Our computing facilities vary widely in scope, geography, and applications. Most of the computers are administered by the Computing Department, however a large number of machines that are dedicated to accelerator and beamline controls are administered independently. For the most part, these independent machines use Computing Department facilities for data communications.

The major functions of the Computing Department can generally be divided into the management and support of the following three areas of computing:

1) Data acquisition using mini-computers. (generally Digital Equipment Corporation PDP-11 and VAX systems) dedicated to the acquisition of data on physics experiments located in the experimental areas of the Laboratory.

2) Data analysis performed on our Control Data Cyber 175 computers.

3) Laboratory support computing including business applications, word processing, and data base applications. (Mostly performed on our IBM 4331 computer system.)

Some of these functions require more data communications capabilities than others. For example, there is a very limited need currently for communications on the data acquisition computers, while the data analysis machines depend heavily on data communications.

The Computing Department, in attempting to optimize utilization of all of the facilities, has allowed and will encourage applications to cross boundaries between machines that generally are used for specific purposes. So for example, we find most of our business applications running on our IBM machine; however word processing is generally accomplished on our CDC computers. These semi-related applications crossing machines would normally proliferate redundant data communications networks to be built with separate cabling, terminals, and modems.

5.2

DEFINING FERMILAB'S NETWORKING PROBLEMS

My discussions of data communications history come from first person experience. At one time FERMILAB's only data communications consisted of several modems connected to a PDP-10 computer system. The main computer facility was strictly batch, and did not have any interactive terminals connected to it. The need for interactive computing came about when we upgraded our main computer system in 1979, and committed to an interactive computer operating system.

No one was really sure how well interactive computing would be accepted by a computing community that was accustomed to using card decks as the only means of program storage and maintenance. A short time later, our old IBM computer system that ran most of our business applications required replacement, and this was acomplished with a new processor and operating system that would also allow for interactive use. Additionally, we were supporting several DEC PDP-11 computer systems for program development, and there were going to be several DEC VAX-780 systems delivered within a years time period, all to be used interactively. These factors determined our major needs for networking. As the number of computer systems that were going to run interactively increased, the real networking problems we faced were to provide a framework that would minimize the networking costs for supporting slow speed terminal connections to computer systems instead of interlinking the computer systems. We decided that our needs for shared peripherals and/or high speed interprocessor communications links would be best served through other network facilities.

By the definition of the problem, the only solution (in 1979) was a star network centered around a data PABX (or port selector).

5.2.1 PROBLEMS WITH THE MEDIUM OF THE NETWORK

As stated previously, the use of a port selector implies the use of TPW's for a medium, and baseband utilization of the medium. The difficulties that had to be overcome with the cabling were all of the typical problems that are related with using TWP's as a medium, and they are as follows;

1) Slow speed.
2) Noise immunity. (Shielding)
3) High cost of leasing phone circuits for local data connections.
4) Expandable distribution of the medium.
5) Limited transmission distances with RS-232 compatible devices.

All of these items had to be addressed before a solid committment could be made for a single large network.

The slow speed problems of TPW's were not really an issue with our system for several reasons. First of all our network was going to be centered around our large CDC computing facility. To simplify our configuration of computer ports, and to allow for more of them, it was decided to limit normal interactive computing to 1200 baud which happened to be the fastest speed the CDC system could perform autobaud recognition. This limit was also compatible with the fastest asynchronous modem that could be used on a voice grade line. Even so, we decided that our network wiring had to to support a minimum of 9600 baud at the maximum distance point in the local network.

Noise immunity was the most important factor in deciding how the network should be cabled. Our limited experience with direct connection of terminals and computer ports convinced us that transmission errors could not be tolorated. Troubleshooting transmission errors were very difficult and time consuming.

Leasing telephone wires within your own building, for your our computer, and to your own terminals just did not seem to be the most cost effective method of distribution for our network. Additionally, our telephone trunks were strained to capacity and data connections would just force the telephone company to install more of their own cable in our buildings.

Because we did not know how many connections we would eventually need, whatever cabling scheme we decided on would require the ability to expand it to accommodate any reasonable number of connections.

5.2.2 Problems With A Star Network

Using a PABX usually means that the existing PABX that controls the telephone system is upgraded or replaced so to be able to switch data as well as voice. These schemes, although cost effective in some respects, do place a lot of responsibility in both the switch and the network of cables that serve it. Other factors such as the total switching capacity and switching features have to be managable by the PABX as well. In some cases, data switching may have to be compromised for voice or visa versa. Maintaining the medium where data may share the same wires as voice complicates the troubleshooting tasks.

One other major drawback to this scheme is that there is now a single point of failure for all communications, and even though the reliability may be great, having to disable voice communications for data troubleshooting or data for voice is not the best utilization for either.

By using a port selector, we could allow any terminal to access any computer system, and use the same wiring for all of the terminals and computers.

5.3

FERMILABS CHOICES

The problems were now clearly defined and they were inherent in the network type we decided on. The medium problems seem to be the most important to solve in that if a suitable medium implementation was not found, the port selector device would not be needed because we would be forced into de-centralizing the network into many individual networks, and thus negate the need for the port selector.

5.3.1 Medium Implementation

In looking for a solution to the medium problem, I discovered that pre-assembled telephone cables could be purchased from several manufacturers. These cables are called connectorized cables and consist of 25 twisted wire pairs with 50 pin connectors on each end. The cables are made from 26 gauge wire and come in various lengths from 10 to 300 feet.

In looking at our network needs, we knew that most of the computer connections would be located within the Central Laboratory Building which contains most of the engineering, scientific, and business activities of Fermilab. This meant that at least half of our network would be located within one to two thousand feet of the central computing facility.

Seeing that the pre-assembled cables could be used to distribute the network within the Central Laboratory, the next thing to do was to assemble a worst case cable situation and study the transmission characteristics. To make a several thousand foot run of cable, several cables with opposite sex connectors were strung together, and actually installed in the building to see if shielding or grounding problems as well as impedance mismatches and reflections would interfere with transmissions. I used all of the instruments at my disposal to evaluate the test run of cable, sweep generators, spectrum analysers, and time domain reflectometers. All of the test indicated that the cable itself even with the interconnections of many cables could support baseband transmissions at data rates at least an order of magnitude greater than our maximum anticipated speed. In the process of my testing, I also discovered that telephone distribution pannels with connectors that mated with the connectorized cables could also be purchased. These two standard telephone cabling items used together would allow me to assemble thousands of wire pairs for thousands of feet without soldering a single connection. For medium distribution, the only missing element was a scheme for dividing the geography of the building into logical divisions that would allow easy identification of any connection. A numbering system of trunks, cables and connection was established for this purpose. The only hand wiring that had to be done was between the computer end of the trunks which terminated into an additional local standard cable set that takes the punch on telephone connections to individual 25 pin RS-232C connectors. At the other end of the trunk, individual cables were needed to connect the terminals to the trunk cables. Again, local standards were established to allow for color code compatibility.

This entire arrangement allows for easy identification, expansion, and troubleshooting. Each trunk in the system can consist of any number of cables that serve a specific geographical location, and each cable can provide up to 12 terminal connections. (2 TPW's per terminal connection). More important, all of the limitations normally associated with TPW's were now not applicable to our installation. And now, the true test of the mediums implementation could be evaluated. And that of course related to the cost effectiveness of this implementation. Calculations showed that the cost of installation and materials would be paid back within the first years use relative to leasing telephone circuits.

5.3.2 Port Selector Implementation

Now that our own TPW medium for data was going to be independent of the existing telephone system, any advantage that might be gained by integretation of a data switch within the local PABX would be lost. So for our installation, we were only interested in installing a pure data PABX, and of course the ever present cost effectiveness issue had to be addressed. Our needs also dictated that our port selector provide as much flexibility as possible, again because of our not knowing exactly how large or complex the network would become.

Our selection process and proceedures are inappropriate for discussion in this paper, but we eventually decided on purchasing a Micom systems port selector. I will be mentioning features that specifically will refer to Micom's device at this point. Most other manufacturers have similiar features, and the one's I will mention are the one's that have become important to us and are useful to use as a basis for comparison of similiar equipment.

The most important issue that had to be addressed was the lack of redundancy associated with a star network. The port selection device that we selected has redundancy both in the logic and power supplies. The logic allows for switching between the primary and secondary systems that are identical and ready to use. The power supplies automatically switch to the secondary power supply if the primary should fail. There is also redundancy in the modules that actually do the switching between the terminal lines and computer ports. One further level of protection comes in the fact that all of the modules that drive the lines or ports are interchangeable, so a minimal number of these boards have to be held as spares. Because our port selector device is only concerned in switching data and not telephones as well, it is insensitive to maintenance and failures related to our telephone system.

The port selector device provides quite a lot of control, monitoring, and troubleshooting tools that one would not normally have. These features, in addition to the basic switching scheme, provide complete computer independent network management.

The port selector, with its built in redundancy, has proven to be far more reliable than any of the equipment it serves. In over three years of operation, only minutes of down time are related to the operation of the switch. Every component failure of the system involved singular components that were covered by the built in redundancy. So our greatest concern with having a single point of failure in a star network has been put at ease.

The cost savings involved with the use of the port selector are widespread. The most obvious is that the interface cards that provide the terminal connections are compatible with baseband line drivers so for each terminal connection, only one line driver is required per terminal instead of one at each end of the link. The use of the line drivers gets around the 50 foot limitation of the RS-232 standard. The other major advantage especially for a large time sharing system, is the sharing of communications resources. This sharing comes in the following forms:

1) Computer ports are shared by all terminals so utilization is high.
2) Modems can be shared by several different computer systems.
3) Terminals can access several different computer systems.

This sharing can at least double the effectiveness of all the communications resources if several systems are involved and common elements can be shared.

6.0

CONCLUSIONS

There are many aspects of data communications and networking that I have not discussed, or have just briefly mentioned. I have done this intentionally because my feelings are that the network should be autonomous of specific vendors computer systems whenever possible. All of the networks described in this paper reflect those network systems that can provide this autonomity. I have not mentioned all of the network manufacturer's that can provide vendor independency, but the one's I have mentioned are representative of many. The future of networking will have enough standardization so that networks can become as independent from the computing system as did programming when universal languages were developed to generate machine code.

Although this paper has not emphasized the inevitability of networking's impact on computing, this will happen very soon. This impact will change the way we do our computing and the way our computing is done. De-centralization of computing resources will create different problems that will force us into learning new fields of technology.